Brit. Heart J., 1965, **27**, 424.

EXPERIENCE WITH HYDROGEN AS AN INDICATOR OF LEFT-TO-RIGHT SHUNTS

BY

P. BOPP, PH. BUSSAT, P. R. MORET, P. W. DUCHOSAL, AND R. A. PASCHE

From the Centre de Cardiologie, University Hospital, Geneva, Switzerland

Received July 23, 1964

Detection of intracardiac shunts by means of conventional oximetry, dye dilution curves, nitrous oxide, or krypton gas tests, may be hampered by lack of sensitivity of the method, cost, or complexity of equipment and unreliability of the results.

The hydrogen technique proposed by Clark and Bargeron (1959a, b) and Bargeron, Clark, and McArthur (1960) seems to obviate these disadvantages. The following is a short survey of our experience with more than 450 hydrogen tests performed in 43 subjects.

Subjects and Methods

Our material includes 28 patients without shunts (rheumatic heart disease, 13; essential hypertension, 4; pericarditis, 1; cor pulmonale, 1; congenital heart disease without shunt, 3; subjects without cardiovascular disease, 6), in whom 256 curves were recorded.

We obtained 202 curves in 15 patients with left-to-right shunts (atrial septal defect, 7; ventricular septal defect including one case of maladie de Roger, 6; patent ductus, 1; aorto-pulmonary fistula, 1), ranging from 13 months up to 40 years of age. The shunt was demonstrated either by oximetry, or by dye curves, or by angiography.

Hydrogen was administered through a face mask connected by a switch to a gas container. At a given signal, the subject was requested to take a deep breath; younger children under sedation were given the gas at the moment of inspiration. After inhalation, hydrogen gas immediately crosses the pulmonary capillary membrane and enters the arterial blood. A platinum electrode mounted on an intravascular catheter acts as a hydrogen detector; on contact with the platinum, hydrogen becomes ionized, thus creating an electrical potential which can be recorded.

We used a commercially available electrode catheter* connected through a control-box (Fig. 1A) to an Electronics for Medicine recorder. Two or more curves were systematically recorded at about 30-second intervals in each of the following locations: right and/or left pulmonary artery, right ventricle, right atrium, superior vena cava. Whenever possible, curves were recorded in the left cardiac cavities in patients with septal defects. As many as 21 curves were thus obtained in a single patient with no untoward effect.

A special stylet (Fig. 1B) adaptable to a Seldinger arterial needle was later employed for the detection of gas at a peripheral arterial site; the usefulness of such a time reference has been underlined by Hyman *et al.* (1961). Recently we have started using a thinner platinum electrode probe* which can be introduced through a Cournand needle and may be advanced further up into the aorta.

In the earlier studies, a nasal electrode was employed for the exact timing of inspiration; however, it was soon abandoned, the somewhat greater time accuracy being outweighed by the inconvenience caused to the patient; good approximation was obtained by manually recording the onset of inhalation.

* U.S. Catheter and Instrument Corp., Glens Falls, New York, N.Y.

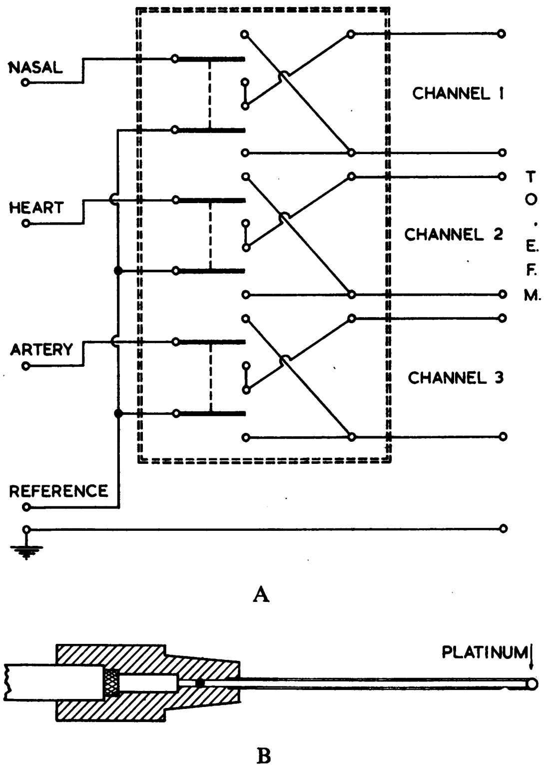

FIG. 1.—(A) Control box. The anterior part of the aluminium box contains three double-pole switches; simultaneous recordings of three different curves are possible; four plug connexions are mounted in the back of the box. Shielded cables are used to connect the platinum electrodes on the patient to the contact box. The latter is connected to the EFM recorder by three cables with shielded double-conductors. (B) Arterial electrode stylet. At the extremity of an 0·8 mm. diameter platinum wire, a little bead of 1·1 mm. diameter is heat-produced. This wire is wrapped in a teflon sheath of 0·9 mm. internal diameter and 1·1 mm. external diameter. The stylet is fixed by glue to a holder which can be adapted to a Seldinger arterial needle.

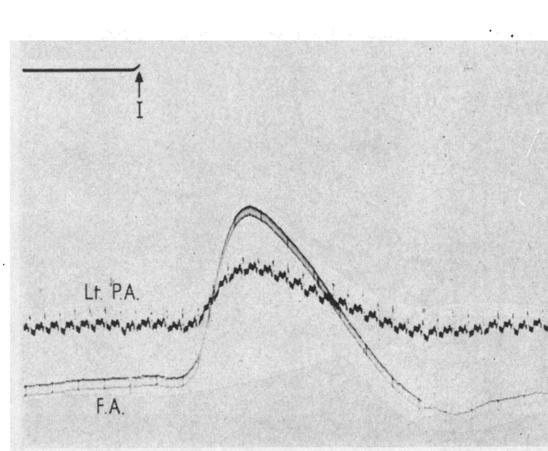

FIG. 2.—False-positive example. Electrode catheter is in left pulmonary artery (Lt. P.A.). Appearance time, 2 seconds. Appearance time in femoral artery (F.A.), 2 seconds. Identical curves were recorded in right ventricle and right atrium. (Recording speed is 10 mm./sec.)

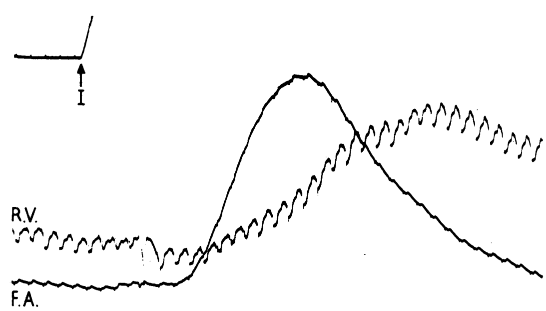

FIG. 3.—Example of a no-shunt case. Appearance time in femoral artery 6 seconds, and in right ventricle 8·5 seconds.

Appearance times in seconds were measured between the beginning of inhalation and the start of the deflection at the intravascular (peripheral arterial and intracardiac) sites.

RESULTS

In all patients except one in the no-shunt group, the appearance time in the pulmonary artery exceeded 4 seconds and ranged generally between 8 and 16 seconds. In one, however, appearance time was unusually short in all locations (pulmonary artery, right ventricle, right atrium), thus suggesting a possible shunt, in spite of a normal oximetry (Fig. 2). This patient had a tight mitral stenosis and he died later of multiple pulmonary infarctions. A careful control at necropsy failed to reveal any congenital malformation (septal defect or abnormal venous return) to explain this phenomenon.

In all the other patients in this group, right cardiac appearance time was greater than 4 seconds, and different from the appearance time noted at the peripheral artery (Fig. 3).

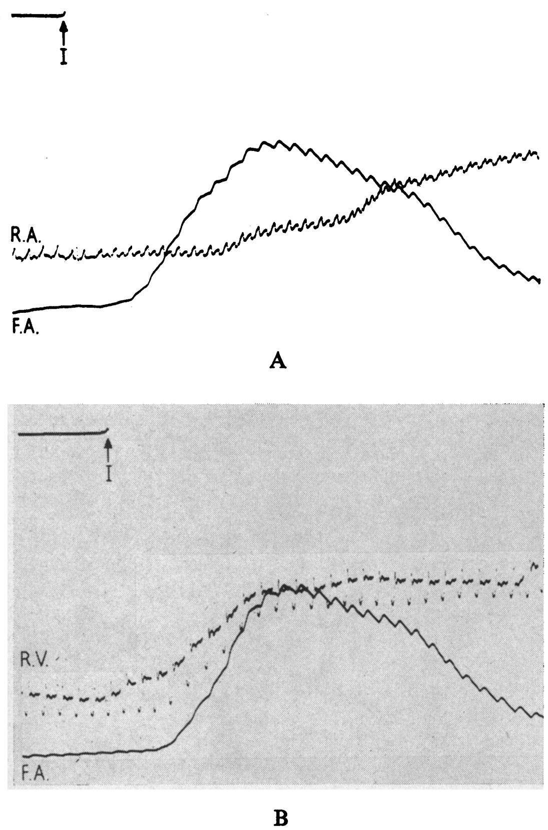

FIG. 4.—(A) Case of ventricular septal defect (Roger). Electrode catheter in right atrium: appearance time in right atrium 7·5 seconds, and in femoral artery 3 seconds. (B) Same patient with electrode catheter in right ventricle. Appearance time in right ventricle 0·5 second and in femoral artery 2·5 seconds.

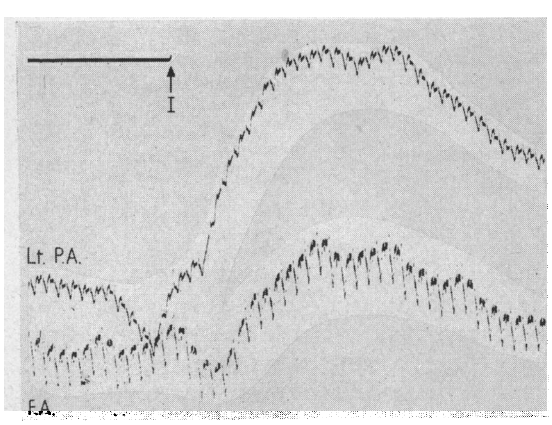

FIG. 5.—Case of patent ductus. Electrode catheter in left pulmonary artery. Appearance time in pulmonary artery is 1 second, and in femoral artery it is 2·5 seconds.

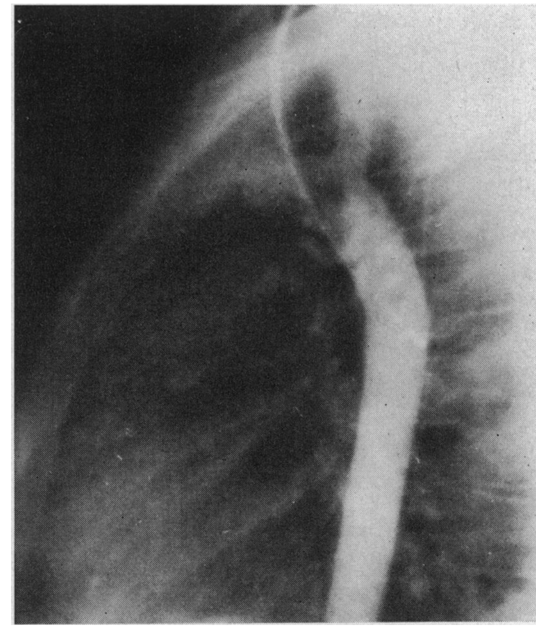

FIG. 6.—Same patient as illustrated in Fig. 5. Aortography showing patent ductus.

Shifts in the baseline due to respiratory variations often interfered with the quality of the recordings at the vena cava and sometimes at the right atrial levels. This was not observed at the other sites. In the shunt group, right heart appearance time of hydrogen in the cavities downstream to the shunt was never greater than 4 seconds. In one patient in this group, a 6-year-old boy with corrected transposition of the vessels and pulmonary stenosis, right ventricular and pulmonary appearance time of 4 seconds suggested a ventricular septal defect, because of a more delayed (8 sec.) appearance time in the right atrium, though no shunt could be demonstrated by oximetry. The hydrogen method enabled us to detect a shunt in two more patients in whom the oxygen values failed to reveal it. The first was an 11-year-old girl with auscultatory findings of a Roger type of ventricular septal defect: hydrogen tests (Fig. 4) confirmed the diagnosis. In the second, a 9 year-old girl, the auscultation was suggestive but not typical of a patent ductus: hydrogen tests performed in the left pulmonary artery enhanced further this suspicion (Fig. 5). However, since a false positive response could not be ruled out, aortography was performed and proved the existence of a ductus (Fig. 6). In the shunt cases, no significant differences in appearance time between the various cavities downstream to the shunt were observed.

Discussion

There is wide agreement among advocates of the hydrogen method that appearance times shorter than 4 seconds are pathognomonic of a left-to-right shunt (Gasteazoro *et al.*, 1963; Hugenholtz *et al.*, 1963). This is also confirmed by our series. As far as we know, however, there has been no published report of a false-positive response such as the one mentioned above. Gasteazoro *et al.* (1963) emphasized the importance of properly checking the location of the electrode catheter in the pulmonary artery: indeed, these authors have demonstrated that false-positive results could be obtained in a wedge position. We also observed this in a few of our patients. However, this would not explain our false-positive response in the right ventricle and atrium. Though possible in the right atrium, it seems unlikely that coronary sinus blood could produce such a response in the ventricle, much less in the pulmonary artery. An artefact cannot be entirely ruled out, but it is not certain; therefore, though the absolute appearance time value does permit, in the vast majority of cases, separation of the shunt from the no-shunt cases, it may occasionally be misleading (Fig. 7A). This led us to use the ratio $\frac{\text{Appearance time (pulmonary artery)}}{\text{Appearance time (femoral artery)}}$, hoping that it might perhaps ensure a better differentiation. This seems to be the case (Fig. 7B).

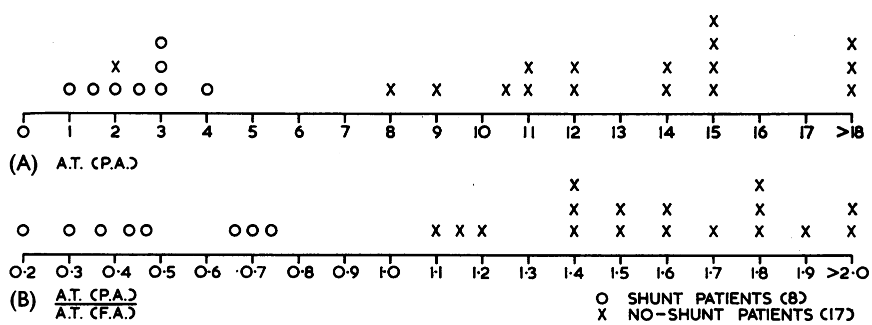

FIG. 7.—(A) Differentiation between shunt and no-shunt patients, using appearance time in pulmonary artery. (B) Differentiation between same patients using $\frac{\text{Appearance time (P.A.)}}{\text{Appearance time (F.A.)}}$ ratio.

As well as allowing a quick detection of left-to-right shunts, hydrogen tests are also helpful in other situations, for example when pulmonary insufficiency is to be demonstrated in cases of patent ductus. Use of a multiple electrode catheter, as proposed by Levy *et al.* (1961) and Martinez-Lopez *et al.* (1962), may then be necessary. Hydrogen tests have been found to be more sensitive than dye curves (Vogel, Grover, and Blount, 1962).

Advantages of the hydrogen method, in addition to its sensitivity, are its simplicity, its low cost, and its instantaneous response. The technique seems to be particularly appropriate in routine studies where a quick check is desired; for this purpose the technique may replace conventional oximetry.

Possibility of visualizing the intracardiac electrocardiogram is of further value on some occasions (Ebstein's disease), as Arcasoy, Guntheroth, and Mullins (1962) have pointed out. It has to be stressed, however, that some precautions must be taken in the grounding of the patient in order to avoid electrocution from use of a cardiac electrode (Weinberg *et al.*, 1962). The danger of explosion can also be minimized by reasonable caution; after carrying out more than 450 tests in this laboratory we have no incident to report to date.

At the present time, the major drawback of the hydrogen method is the lack of quantitation of the results. Attempts are under way here and elsewhere (Hyman, 1961) to alleviate this disadvantage.

SUMMARY

The hydrogen method has proved to be most useful in the detection of small left-to-right shunts. It is a simple, easy, inexpensive, and safe technique if carried out with proper care. The present lack of quantitation should not detract from its excellent qualitative value.

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